U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
CALIFORNIA GEOLOGICAL SURVEY

SCIENTIFIC INVESTIGATIONS MAP 2918

What is a geologic map?

A geologic map shows the distribution of geologic materials and geologic structures that are visible at the Earth's surface.

Geologic materials are the igneous, metamorphic, and sedimentary rocks and surfical sediments that form the landscape all around us. Most geologic maps, like this one, use colors and labels to show areas of different geologic materials, called map units. Geologic structures are the breaks and bends in the geologic materials and are caused by the slow but powerful forces that shape our world. Geologic maps show the location of these structures with different types of lines. Because the Earth is complex, no two maps show the same materials and structures, and so the meaning of the colors, labels, and lines is explained on each map.

This geologic map was made by bringing together and simplifying many separate geologic maps prepared by U.S. Geological Survey, California Geological Survey, and consulting geologists over the past 15 years. You may note some minor discontinuities in the map, mostly in remote areas. These are places where geologists have disagreed on the identity of the geologic materials, and they mark areas where more work needs to be done. All geologic maps can be made even better by further studies.

Why make a geologic map?

An accurate geologic map is needed to understand the Earth's resources and hazards.

A geologic map provides basic data for understanding both past and present-day processes affecting a region of the Earth. This kind of information is important for four main reasons:

(1) To provide geologic information that can help to reduce death and damage caused by geologic hazards such as earthquakes and landslides. Different types of geologic materials can amplify shaking or even liquify during earthquakes. Some also are more likely to produce landslides, or they may contain natural deposits of hazardous asbestos or mercury. A geologic map shows where these types of geologic materials are, as well as the location of faults that might generate earthquakes.

(2) To better find and protect or safely extract geologic resources. Concrete, sand, metals, petroleum, even groundwater, are all important geologic resources, but to benefit society, they first must be found. A geologic map shows the distribution of the rocks and sediments that are most likely to contain these resources. For example, if you needed sand and gravel to make concrete, would it be better to look in an area of solid granite (map unit Kgr) or in an area of loose river deposits (map unit Qha)?

(3) To improve our stewardship of the Earth through informed agriculture, construction, and environmental practices. A geologic map shows the distribution of the types of geologic materials that are likely to produce poor soils that are unsuitable for agriculture (for example, map unit Jsp). It also shows which rocks will provide the safest foundations for buildings and roads, as well as those which can help support important or endangered species.

(4) To help geologists unravel the geologic history of the region. The relations between the geologic materials and structures shown on the geologic map give clues about the sequence of events that happened in the area in the past. An improved understanding of the geologic history helps us to better understand the region's geologic resources and hazards.

Geologic time and the age of rocks

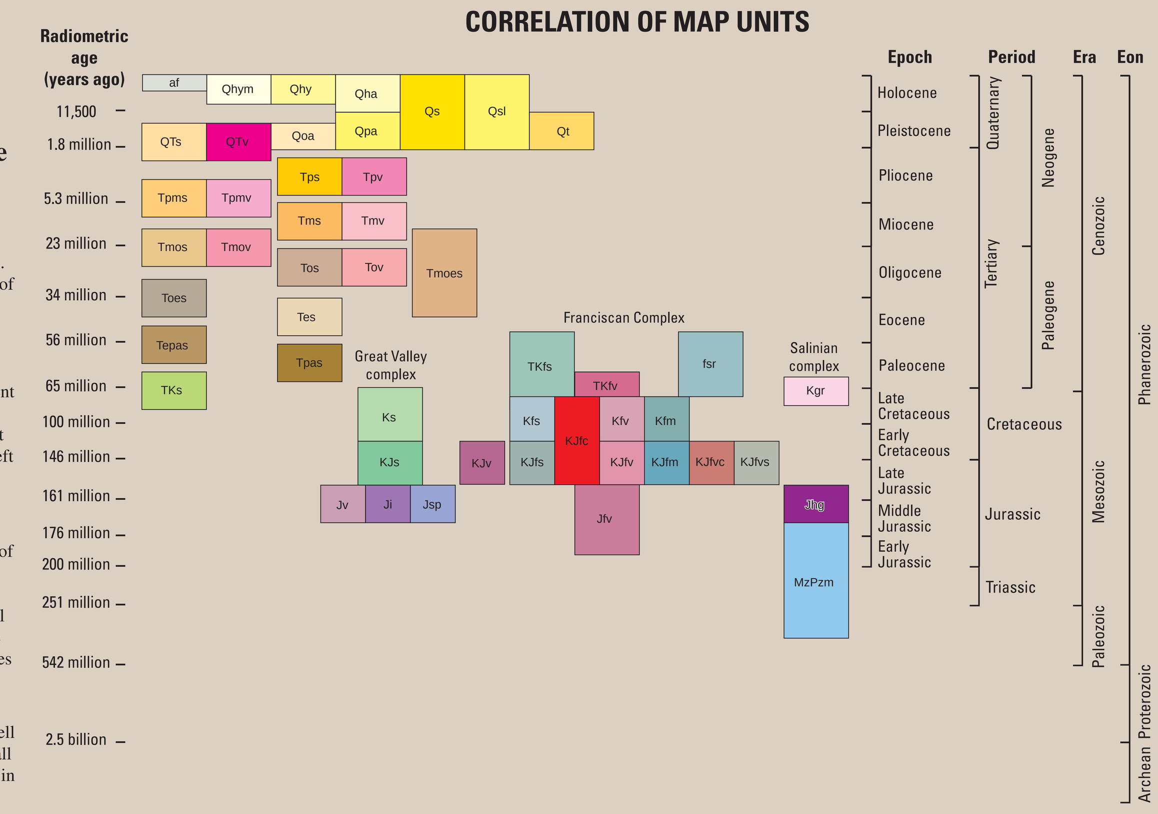
Geologists use fossils to divide Earth history into named intervals, and they use the rate of radioactive decay to determine the numeric age of those intervals.

This map classifies the geologic materials of the San Francisco Bay region by age, dividing them into eons, eras, periods, and epochs of geologic time. Geologists have long observed that fossils vary from the bottom to the top of sedimentary layers, and that there is a consistent pattern to the variation. This observation, combined with the knowledge that younger sedimentary layers are laid down on top of older layers, led geologists to conclude that the fossils in the lowest sedimentary rock layers were the oldest, and that those in the highest layers were the youngest. They then used this consistent pattern of variation, observed in fossils worldwide, to divide geologic time into the named divisions and subdivisions that are used today. In the oldest eon (Archean), only the most primitive lifeforms were present, and these left very few fossils. In the youngest epoch (Holocene), the fossils are very similar to plants and animals living today.

In the 20th century, geologists developed a way to assign numbers to the ages of each fossil-based division of geologic time. By observing the rate of decay of radioactive elements and then by measuring the amounts of both radioactive elements and their decay products in rocks, geologists can calculate a numeric age (called a radiometric age) for the rocks. By careful study of the relations between the fossil-bearing sedimentary rocks and the rocks that have yielded radiometric ages, geologists have calculated the ages of the divisions of geologic time, from the Archean eon, more than 2.5 billion years ago, to the Holocene epoch, less than 11,500 years ago.

The chart on the right shows many of the divisions of geologic time, as well as how the map units fit into these divisions. Although the chart shows all the eons, it shows only the eras, periods, and epochs of the rocks found in the region. The radiometric ages of the boundaries between the divisions also are shown. Notice that geologists have divided the periods of the Cenozoic era in two different ways. Also notice that the oldest rocks in the region are Paleozoic age, and that almost all the rocks are Middle Jurassic age (176-161 million years) or younger.

CORRELATION OF MAP UNITS

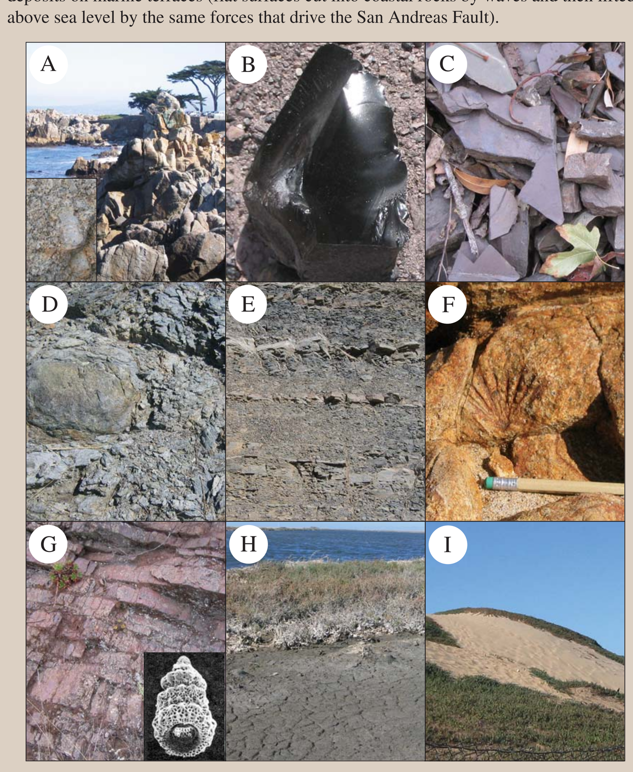


Geologic materials

Geologic materials are the rocks and sediments that make up the land where we live.

The characteristics of geologic materials reflect the processes that form them and the environments in which they form. Geologists divide these materials into three basic rock types. **Igneous** rocks originate as extremely hot melted rock below the Earth's surface. If the melted rock cools slowly under the surface, it forms **plutonic** rock (named after Pluto, the Roman god of the underworld), such as granite. If, instead, the melted rock stays hot and rises to the surface, it can either ooze out or explode to form **volcanic** rock (named after Vulcan, the Roman god of fire), such as basalt and obsidian. When rocks get buried or are pushed deep into the Earth, the pressure and heat changes them into **metamorphic** rocks, such as marble and slate. Serpentinite, the California state rock, is another example of metamorphic rock. **Sediments** are mostly bits and pieces of older rocks that have been transported by wind and water to accumulate on beaches and in sand dunes, on lake and river bottoms, and on ocean floors. Given enough time, sediments may be buried under subsequent accumulations and then squeezed or cemented together to form **sedimentary** rocks, such as sandstone and shale. The remains of plants and animals get caught up in these accumulations to form fossils, which are found only in sediments and sedimentary rocks. Although fossils usually are sparse, a few sedimentary rocks are made almost entirely of fossils; for example, chert is made from millions of tiny plankton fossils.

This map shows where the different rock types are found in the San Francisco Bay region. The map also shows accumulations of young sediments that have not yet been converted to rocks, such as sand dunes, bay mud, stream deposits (alluvium), and deposits on marine terraces (flat surfaces cut into coastal rocks by waves and then lifted above sea level by the same forces that drive the San Andreas Fault).



Examples of geologic materials in the San Francisco Bay region (their basic rock types and map units are given in parentheses). (A) Granite (plutonic, Kgr); inset shows a close-up of the large mineral crystals that make up granite. (B) Obsidian (volcanic, Tpmv). (C) Slate (metamorphic, Kfm). (D) Serpentinite (metamorphic, Jsp). (E) Thin layers of sandstone and shale (sedimentary, KJs). (F) Fossil-bearing sandstone (sedimentary, Tos). (G) Chert (sedimentary, KJfc); inset shows a microscopic view of one of the millions of plankton fossils (order Radiolaria) that make up chert. (H) Bay mud deposits (sediments, Qhym), which over geologic time may be buried by other deposits, compacted, and transformed into shale (sedimentary). (I) Sand dunes (sediments, Qs).

Rocks from somewhere else

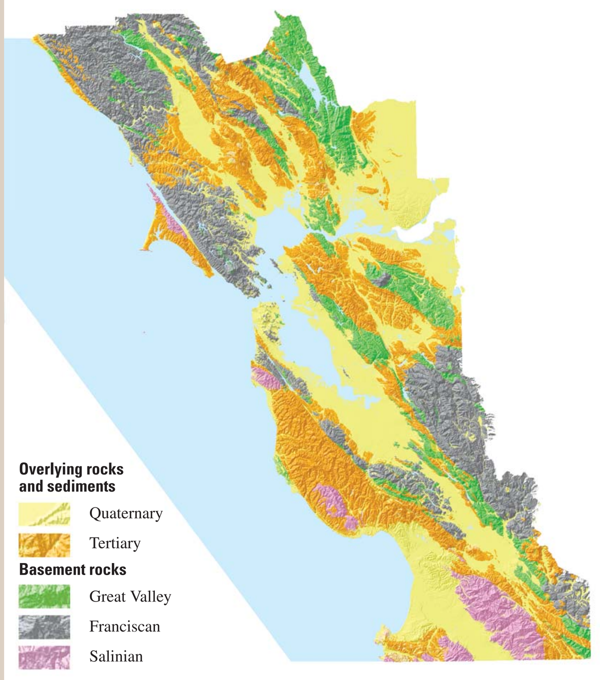
North America once ended far to the east, where the Sierra Nevada is today. All the basement rocks of the San Francisco Bay region have been added to North America, brought by tectonic motion.

Although it is hard to imagine, geologists have determined that the western coastline of North America was once where the Sierra Nevada foothills are today. At that time (the Middle Jurassic period, 171-161 million years ago), the coastline was dominated by a chain of volcanic mountains like those of the Andes Mountains in South America today. The position of the San Francisco Bay region probably was occupied by volcanic islands like those of the Aleutian Islands in Alaska today. However, the huge tectonic plates that make up the Earth's crust constantly move around, forming, colliding, and recycling into the Earth's interior. By the end of the Jurassic period, the volcanic islands had been moved east by this relentless motion. In turn, Jurassic-age and younger rocks have been transported here from elsewhere.

These transported rocks, which are the oldest (basement) rocks of the region, form three groups, each having a distinct history. The first group is the Great Valley complex, probably transported to the San Francisco Bay region and added to North America in Late Jurassic time (about 150 million years ago) along a subduction zone. A subduction zone is the boundary between two converging tectonic plates, where rocks of one plate slide under another plate and down into the Earth's interior. Frequently, some of the rocks on the downgoing plate are scraped off and added to the overlying plate, and rocks of the Great Valley complex were added to North America in this way. The second group is the Franciscan Complex, parts of which originated as far south as the equator. Between Middle Jurassic time (176-161 million years ago) and Miocene time (23-5.3 million years ago), Franciscan Complex rocks were pushed under and scraped off onto rocks of the Great Valley complex along a second subduction zone. In Oligocene time (about 34 million years ago), plate motion changed, and this second subduction zone began to be replaced by the San Andreas Fault system. The third group of basement rocks in the region is the Salinian complex, made up of slivers of continental rocks that have been moved here from southern California by the motion of the San Andreas Fault system. The resulting mosaic of basement rocks, and the younger rocks and sediments deposited over them, is shown below.

This diagrammatic physical map shows what the western edge of North America looked like 176-161 million years ago (Middle Jurassic time). The present-day positions of San Francisco and Los Angeles, as well as the California state line and the Mexican border (highlighted in yellow), are shown for reference.

At that time, the coastline of North America was about 100 miles east of its present position, and two subduction zones were offshore. The Aleutian-type volcanic islands that were in the San Francisco Bay region at that time moved eastward to the eastern subduction zone, where they were scraped off and added to North America. At the same time, Jurassic-age rocks that are now in the San Francisco Bay region came together along the western subduction zone, and these rocks also moved east and eventually were added to North America.

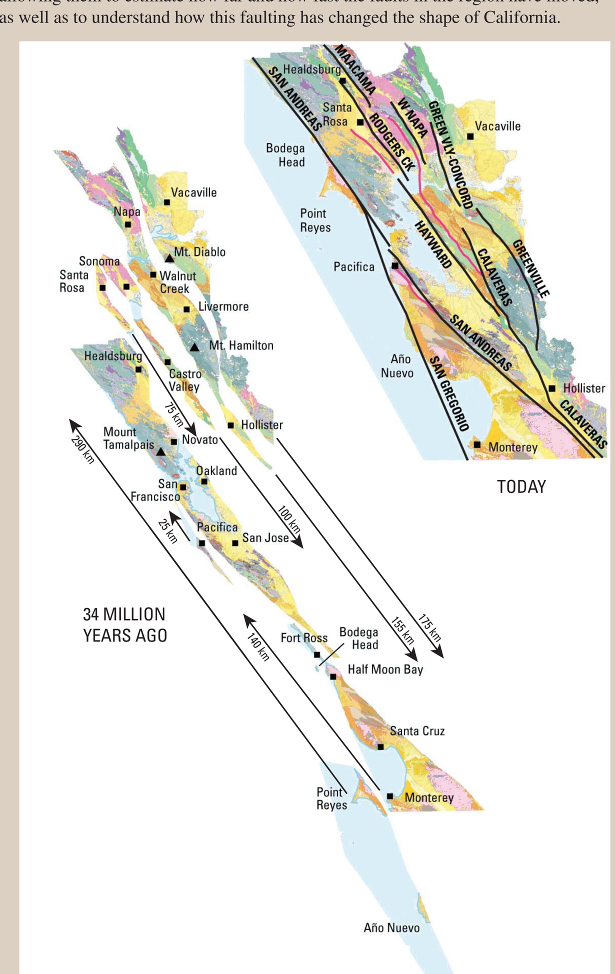


Map of the San Francisco Bay region, showing basement rocks and overlying Tertiary rocks and Quaternary surficial sediments.

Sliced up

Many faults make up the plate boundary, and they slide blocks of rocks like a deck of cards on edge, pulling them apart or bringing them together over great distances.

In addition to sliding the rocks of the Salinian complex north from southern California, the San Andreas Fault system has broken up and moved the rocks of the region. Although the San Andreas Fault itself is often thought of as the boundary between the Pacific and North American plates, many faults in the region work together to take up the motion of the plates sliding against each other. Today these faults, which are found from the Pacific Ocean to Mount Diablo, are moving together about an inch and a half a year (about one-billionth of a mile per hour). The movement of all these faults over geologic time has sliced up many rock bodies and moved the pieces far apart. For example, Eocene sedimentary rocks located south of Monterey are the same deposit as those found at Point Reyes, sliced up and moved apart by the San Gregorio Fault. Many more offset rock bodies have been recognized by geologists, allowing them to estimate how far and how fast the faults in the region have moved, as well as to understand how this faulting has changed the shape of California.

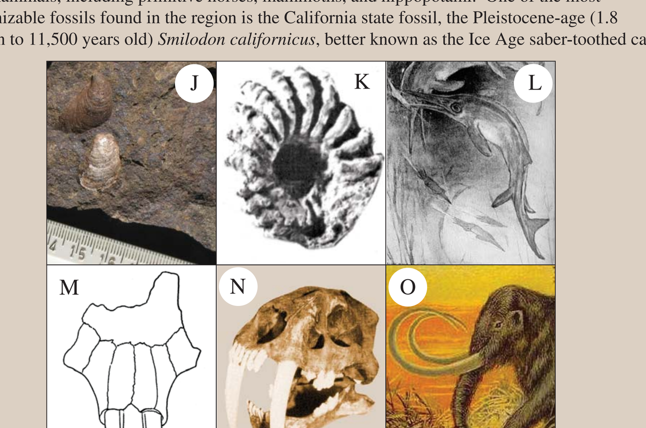


These maps show how far the rocks of the San Francisco Bay region have slid along the faults of the San Andreas Fault system, beginning about 34 million years ago (lower left) and continuing until today (upper right). The arrows show the distance that the faulted blocks of rocks have moved relative to the central block that contains San Francisco, Oakland, and San Jose. The main active faults of the San Andreas Fault system are shown on the present-day map as black lines. Faults that were once important but are no longer active are shown in magenta.

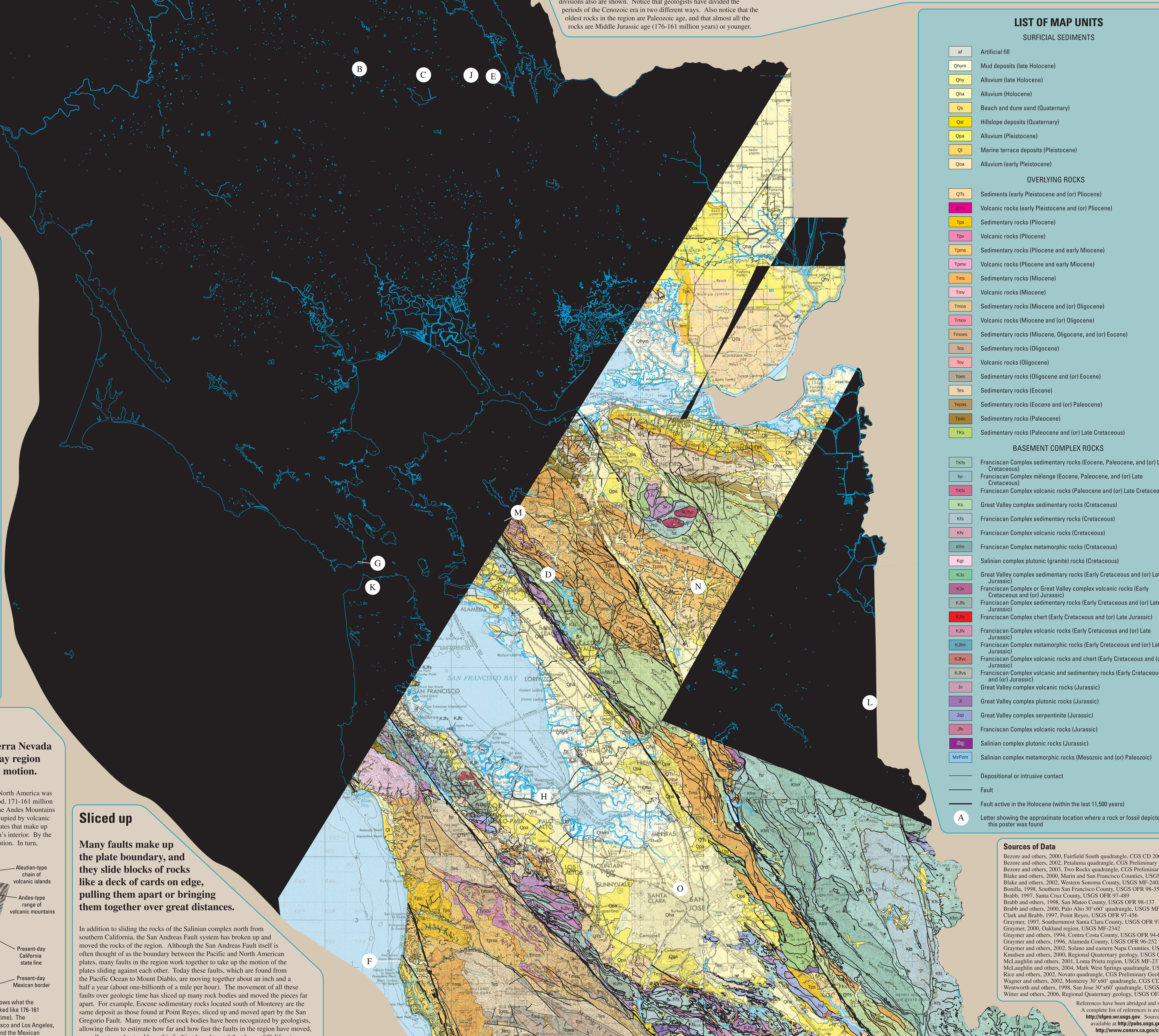
Why are there no dinosaur fossils in the San Francisco Bay region?

Dinosaur-age rocks in the region all formed in the ocean.

Dinosaur fossils can only be found in sedimentary rocks that formed at the time the dinosaurs were living (the Mesozoic era, 251-65 million years ago). The shapes of dinosaur fossils suggest to geologists that the dinosaurs were land animals. However, all Mesozoic sedimentary rocks in the region were deposited in an ancient ocean, and so there can be no dinosaur fossils. How do we know that the Mesozoic sedimentary rocks were deposited in the ocean? Because fossils that have been found in them consist exclusively of marine animals. The oldest land-animal fossils found in the region are Miocene-age (23-5.3 million years old) mammals, including primitive horses, mammoths, and hippopotami. One of the most recognizable fossils found in the region is the California state fossil, the Pleistocene-age (1.8 million to 11,500 years old) *Smilodon californicus*, better known as the Ice Age saber-toothed cat.



Examples of fossils from the San Francisco Bay region. Mesozoic fossils are all marine, such as (J) Jurassic "clams" (mollusks, genus *Buchia*), (K) a Cretaceous ammonite, and (L) a Cretaceous ichthyosaur similar to the one pictured here. Land-animal fossils are all Cenozoic in age, such as (M) part of the Miocene beaver skull shown in this drawing, (N) a Pleistocene saber-toothed cat, and (O) a Pleistocene mammoth similar to the one in this drawing.



LIST OF MAP UNITS

SURFICIAL SEDIMENTS

Unit	Description
af	Artificial fill
Qhym	Mud deposits (late Holocene)
Qhy	Alluvium (late Holocene)
Qha	Alluvium (Holocene)
Qs	Beach and dune sand (Quaternary)
Qsl	Hillslope deposits (Quaternary)
Qpa	Alluvium (Pleistocene)
Qt	Marine terrace deposits (Pleistocene)
Qoa	Alluvium (early Pleistocene)

OVERLYING ROCKS

Unit	Description
QTs	Sediments (early Pleistocene and (or) Pliocene)
QTv	Volcanic rocks (early Pleistocene and (or) Pliocene)
Tps	Sedimentary rocks (Pliocene)
Tpv	Volcanic rocks (Pliocene)
Tpms	Sedimentary rocks (Pliocene and early Miocene)
Tpmv	Volcanic rocks (Pliocene and early Miocene)
Tms	Sedimentary rocks (Miocene)
Tmv	Volcanic rocks (Miocene)
Tmos	Sedimentary rocks (Miocene and (or) Oligocene)
Tmov	Volcanic rocks (Miocene and (or) Oligocene)
Tmoes	Sedimentary rocks (Miocene, Oligocene, and (or) Eocene)
Tos	Sedimentary rocks (Oligocene)
Tov	Volcanic rocks (Oligocene)
Toes	Sedimentary rocks (Oligocene and (or) Eocene)
Tes	Sedimentary rocks (Eocene)
Tepas	Sedimentary rocks (Eocene and (or) Paleocene)
Tpas	Sedimentary rocks (Paleocene)
TKs	Sedimentary rocks (Paleocene and (or) Late Cretaceous)

BASEMENT COMPLEX ROCKS

Unit	Description
TKfs	Franciscan Complex sedimentary rocks (Eocene, Paleocene, and (or) Late Cretaceous)
fsr	Franciscan Complex mélange (Eocene, Paleocene, and (or) Late Cretaceous)
TKfv	Franciscan Complex volcanic rocks (Paleocene and (or) Late Cretaceous)
Ks	Great Valley complex sedimentary rocks (Cretaceous)
Kfs	Franciscan Complex sedimentary rocks (Cretaceous)
Kfv	Franciscan Complex volcanic rocks (Cretaceous)
Kfm	Franciscan Complex metamorphic rocks (Cretaceous)
Kgr	Salinian complex plutonic (granite) rocks (Cretaceous)
KJs	Great Valley complex sedimentary rocks (Early Cretaceous and (or) Late Jurassic)
KJv	Franciscan Complex or Great Valley complex volcanic rocks (Early Cretaceous and (or) Jurassic)
KJfs	Franciscan Complex sedimentary rocks (Early Cretaceous and (or) Late Jurassic)
KJfc	Franciscan Complex chert (Early Cretaceous and (or) Late Jurassic)
KJfv	Franciscan Complex volcanic rocks (Early Cretaceous and (or) Late Jurassic)
KJfm	Franciscan Complex metamorphic rocks (Early Cretaceous and (or) Late Jurassic)
KJfvc	Franciscan Complex volcanic rocks and chert (Early Cretaceous and (or) Jurassic)
KJfvs	Franciscan Complex volcanic and sedimentary rocks (Early Cretaceous and (or) Jurassic)
Jv	Great Valley complex volcanic rocks (Jurassic)
Ji	Great Valley complex plutonic rocks (Jurassic)
Jsp	Great Valley complex serpentinite (Jurassic)
Jfv	Franciscan Complex volcanic rocks (Jurassic)
Jhg	Salinian complex plutonic rocks (Jurassic)
MzPzm	Salinian complex metamorphic rocks (Mesozoic and (or) Paleozoic)

Depositional or intrusive contact

Fault

Fault active in the Holocene (within the last 11,500 years)

A — Letter showing the approximate location where a rock or fossil depicted on this poster was found

Sources of Data

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References have been abridged and summarized. A complete list of references is available at **http://sfgeo.wr.usgs.gov**. Source maps are available at **http://pubs.usgs.gov** and **http://www.consrv.ca.gov/cgs**

Learn more about it

Visit our website to see more maps, photos, diagrams, downloads, and information about geologic maps and other aspects of the geology of the San Francisco Bay region.

http://sfgeo.wr.usgs.gov

Base map extracted from U.S. Geological Survey 1:250,000-scale Digital Raster Graphics (DRG), Monterey, CA, 1998; Sacramento, CA, 1998; San Francisco, CA, 1998; San Jose, CA, 1998; and Santa Rosa, CA, 1998. Original 1:250,000-scale published maps from U.S. Geological Survey, Monterey, CA, 1974; Sacramento, CA, 1970; San Francisco, CA, 1978; San Jose, CA, 1969; and Santa Rosa, CA, 1980

Universal Transverse Mercator Projection, Zone 10 North

APPROXIMATE MEAN DECLINATION, 2006

SCALE 1:275 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 KILOMETERS

MAP LOCATION

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1906 Earthquake Centennial Alliance
http://1906centennial.org

Geologic Map of the San Francisco Bay Region

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